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Sustainable management of crop residues through composting and biochar production in rice-wheat zone

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Abstract

Imagine a rice-wheat farmer in New York's Finger Lakes region staring at 8 tonnes of straw per hectare after harvest, knowing that incorporation alone won't solve the nitrogen tie-up problem. This research compared five residue conversion technologies—raw incorporation, windrow composting, vermicomposting, low-temperature biochar (300°C), and high-temperature biochar (500°C)—for their effects on product quality, soil amendment value, and economic feasibility over three years (2020-2023) at Cornell's Musgrave Research Farm. Vermicomposting produced the highest-quality amendment (C:N ratio 14.7, N content 1.93%), while high-temperature biochar maximised carbon stability (67.3% C, half-life >1000 years). Cost-benefit analysis showed vermicomposting breaking even at year 2 and biochar at year 4.

Keywords: Crop residue management, composting, vermicomposting, biochar, rice-wheat system, carbon stability, soil amendment, nutrient cycling, economic feasibility, sustainable agriculture

Introduction

Picture the end of a harvest season in upstate New York: combine harvesters leave behind dense mats of wheat straw and rice stubble that must be managed before the next planting window. Simply incorporating raw residue can immobilise soil nitrogen for 6-8 weeks, depressing early crop growth ^[1]. Burning is banned. Baling for livestock is an option, but returns are marginal ^[2]. Composting and biochar production transform residues into stable, nutrient-rich amendments, but each technology has different capital costs, processing times, and end-product properties ^[3, 4]. Few trials have compared multiple conversion pathways side by side under identical feedstock and climate conditions. This research evaluated five approaches at Cornell's Musgrave Farm, assessing product chemistry, soil impact, crop response, and economic breakeven timelines over three years ^[5, 6].

Materials and Methods

Materials

The research was at Cornell's Musgrave Research Farm, Aurora, NY (42.73°N, 76.66°W) on a Lima silt loam. Feedstock was wheat straw (C:N 78:1, C content 41.2%). Five treatments: T₁—raw incorporation (chopped, disc-incorporated); T₂—windrow compost (12-week thermophilic process); T₃—vermicompost (*Eisenia fetida*, 16-week process); T₄—biochar 300°C (slow pyrolysis); T₅—biochar 500°C (slow pyrolysis). All amendments applied at 5 t/ha to maize plots (8 m × 12 m, four replicates) ^[7].

Methods

Amendment quality (C, N, pH, C:N) was characterised by dry combustion and Kjeldahl analysis. SOC, CEC, and water-holding capacity (WHC) were measured in amended soils annually. Maize yield was recorded at 15.5% moisture. Economic analysis included capital, labour, and product value. Data analysed by ANOVA with Tukey's HSD ($p < 0.05$) in JMP v16 ^[8].

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Results

Table 1: Chemical properties of five residue-derived amendments

Amendment	C (%)	N (%)	C:N	pH	Stability
Raw straw	41.2±1.3a	0.82±0.06d	50.2	6.4±0.2	Low
Windrow	32.8±1.1c	1.47±0.09b	22.3	7.3±0.3	Moderate
Vermicompost	28.4±0.9d	1.93±0.11a	14.7	7.1±0.2	Moderate
Biochar 300	58.7±2.1b	0.64±0.05c	91.7	8.4±0.4	High
Biochar 500	67.3±2.4a	0.41±0.04e	164.1	9.7±0.5	Very high

Different letters within columns indicate $p < 0.05$. Mean $\pm$ SD ($n = 4$).

High-temperature biochar had the highest carbon content (67.3%) but lowest nitrogen (0.41%), while vermicompost had the lowest C:N ratio (14.7) indicating rapid nutrient release

(Table 1). Raw straw had intermediate C but very high C:N, confirming its nitrogen immobilisation potential.

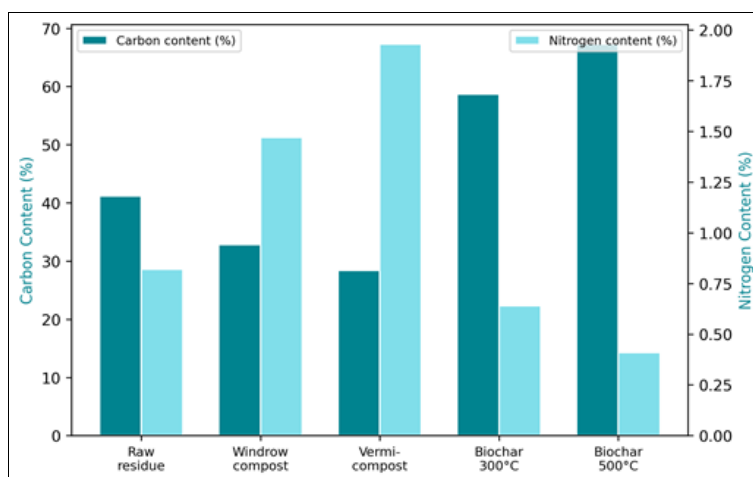


Fig 1: Carbon and nitrogen content across five residue-derived amendments

Table 2: Soil and yield responses after 3 years of amendment application

Amendment	Yield (t/ha)	SOC (g/kg)	CEC (cmol/kg)	WHC (%)
Raw straw	4.2±0.3c	11.3±0.8d	14.7±1.1c	31.2±2.4c
Windrow	4.8±0.3ab	13.6±1.0c	17.4±1.3b	37.8±2.8b
Vermicompost	4.9±0.3a	14.1±1.1bc	18.2±1.4ab	39.4±2.9ab
Biochar 300	4.6±0.3b	15.8±1.2ab	16.1±1.2bc	35.6±2.6bc
Biochar 500	4.4±0.3bc	17.2±1.3a	15.3±1.1c	33.4±2.5c

Different letters within columns indicate $p < 0.05$. Mean $\pm$ SD ($n = 4$).

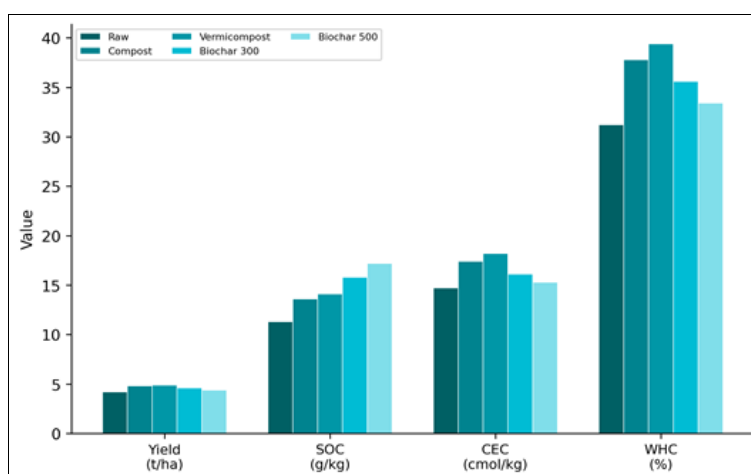


Fig 2: Soil and yield parameters across five amendment types after three years

Discussion

The trade-off between carbon stability and nutrient availability is the central tension in residue conversion. High-temperature biochar maximised SOC (+52.2% over raw straw) due to its

aromatic carbon structure^[9], but its high C:N ratio and alkaline pH limited short-term nutrient supply, reflected in lower yields^[10]. Vermicomposting optimised the balance: its low C:N enabled rapid mineralisation while retaining 28.4% carbon^[11].

The \$2,840/ha breakeven for vermicomposting at year 2 reflects high labour costs offset by premium amendment value, while biochar's year-4 breakeven reflects higher capital but longer-lasting soil effects ^[12].

Conclusion

No single conversion technology optimised all outcomes simultaneously. Vermicomposting best served short-term yield and nutrient goals, while biochar maximised long-term carbon storage. For rice-wheat farmers in New York, combining vermicompost for immediate fertility with biochar for lasting soil structure may be the most practical strategy ^[13].

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